Remedial Planning Activities at Selected
Uncontrolled Hazardous Substance Disposal
Sites in the Zone of Regions IX and X

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NEWMARK Groundwater Contamination Superfund Site

NEWMARK Operable Unit
RI/FS Report

Volume 3: Appendix J

Contract No. 68-W9-0054/WA No. 54-10-9LJ5

Team Subcontractors:

B & V Waste Science and Technology Corp.
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FOREWORD

The Newmark Project Flow Model Technical Memorandum, Part 1, currently included in the Newmark Operable Unit RI/FS Report as Appendix J, was submitted for EPA review (DCN #2755) on October 21, 1991 as Newmark Groundwater Contamination Superfund Site Preliminary Steady-State Model Technical Memorandum, Vol. I through Appendix A.

As it was a stand-alone document at time of submission, all section, figure, and table references remain self-contained.

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Newmark Project Flow Model Technical Memorandum

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PART I

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FORWARD

The Newmark Project Flow Model Technical Memorandum, Part 1, currently included in the Newmark Operable Unit RI/FS Report as Appendix J, was submitted for EPA review (DCN #2755) on October 21, 1991 as Newmark Groundwater Contamination Superfund Site Preliminary Steady-State Model Technical Memorandum, Vol. I through Appendix A.

As it was a stand-alone document at time of submission, all section, figure, and table references remain self-contained.

1.1 INTRODUCTION

This technical memorandum has been requested by the U.S. Environmental Protection Agency (EPA) under the Alternative Remedial Contracting Strategy (ARCS) contract with URS. It was requested by the EPA Remedial Project Manager (RPM) under task 1.3 of the Newmark Groundwater Contamination project Statement of Work (SOW) and is one of the final deliverables of Phase I (Scoping Phase).

In this memorandum, Section 1.2 will describe the data collected during Phase I. Section 1.3 will discuss the importance of the various model stages employing the Fortran 77 program MODFLOW. MODFLOW is a modular, three-dimensional, finite-difference groundwater flow model developed by M.G. McDonald and A.W. Harbaugh (1984). The version used during this study was rewritten in Fortran 77 and updated by the authors in 1988. The 1988 version of MODFLOW has been further modified during the course of this project to accommodate debugging, calibration, and incorporation of site specific geologic and hydraulic data. The customized groundwater flow model used in this study will be referred to as the project flow model in this memorandum. The model stages include the following:

- Development of the conceptual model.
- Preparation of the input data for the preliminary steady-state model.
- Model calibration for both the steady-state and transient models.
- Verification of the model.
- Predictive phase.
- Sensitivity analyses.

Section 1.4 will review the conceptual model. Particularly, the study area and model area will be differentiated, the geology and hydrogeology will be described, and the grid system for the steady-state model will be described. Section 1.5 will discuss in detail preparation of the input data for simulation of the preliminary steady-state model. This section will include descriptions of the hydrogeologic layers, boundary conditions, initial head conditions, percolation basins and ponds, hydraulic conductivity and transmissivity values, well pumpage and vertical leakance values used in the model simulations. Section 1.6 will briefly summarize the revisions and results for each model run. Section 1.7 will describe anticipated modifications that will be made to the input data and boundary conditions for the continued calibration of the steady-state model. Section 1.8 will discuss the recommendations for three additional model stages. Section 1.9 will summarize the data collection effort, preparation and status of the preliminary steady-state model and site-specific geologic and hydrogeologic concepts developed during the preparation and modeling.

1.1.1 MEMORANDUM OBJECTIVES

Phase I of this project entailed gathering existing data, preparing a conceptual model and preliminary groundwater flow model, and recommending and identifying additional project data needs. Currently, the preliminary steady-state groundwater flow model is undergoing calibration. The preliminary steady-state model will be modified and calibrated and a transient groundwater flow model will be simulated. The resulting transient model will be revised and optimized with additional data and information collected during the RI.

The objectives of this memorandum are the following:

- Describe the basic phases of the flow model study;

- Describe the preparation of the preliminary steady-state model;

- Relate the status of the preliminary steady-state model;

- Describe any anticipated modifications to the input data and boundary conditions of the preliminary steady-state model;

- Discuss additional modeling phases that may be useful in the assessment of the plume and aquifer system; and

- Summarize site-specific geologic and hydrologic concepts developed during the preparation and modeling of the preliminary model.

1.1.2 BACKGROUND

A number of municipal water-supply wells (municipal wells) in the northwestern region of the City of San Bernardino, California, have been contaminated by organic solvents. Trichloroethylene (also known as trichloroethene or TCE) and tetrachloroethylene (also known as perchloroethylene or PCE) were detected at concentrations exceeding federal and state action levels for public drinking water supplies. The highest levels of TCE and PCE were found in four wells of the Newmark Municipal Wellfield (Newmark Wellfield). Newmark Wellfield is located adjacent to a suspected source of TCE/PCE contamination.

The California Department of Health Services, Toxic Substances Control Division (DHS-TSCD) and Office of Drinking Water (DHS-ODW); the Regional Water Quality Control Board (RWQCB), Santa Ana Region; and the City of San Bernardino have been active in investigating the nature and source of the contaminant plume threatening the City's water-supply wells. The City of San Bernardino is currently treating the contaminated groundwater from water-supply wells that were previously closed. However, additional water-supply wells, including those of the City of Riverside, are threatened by the advancing contaminant plume.

As part of the responsibility and authority under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), EPA has initiated this focused RI/FS of the Newmark Groundwater Contamination Superfund site to identify long-term solutions to this threat and select an effective remedial action. The overall long-term activities associated with the project will be to fulfill the following objectives: (1) control plume migration through the design of an effective system of extraction wells and treatment facilities; and (2) identify and control the source(s) of the contamination. The ultimate objective of the RI/FS portion of this project is to provide a basis for selection of a remedy that meets the objectives so remedial design and construction will be focused.

1.1.3 OBJECTIVES OF MODEL STUDY

Before remediation can be initiated and prove effective, three questions concerning the aquifer and contaminant plume conditions need to be answered: What is the extent and location of contamination; what are the individual movement patterns of PCE and TCE in the groundwater; and what is the overall configuration of the groundwater systems.

The U.S. Geological Survey (USGS) groundwater flow model MODFLOW (McDonald and Harbaugh, 1988) is being used to simulate the pertinent groundwater flow conditions. Once the overall pattern and elevations of the groundwater flow system are simulated for both steady-state and transient conditions, MODFLOW can be used in a predictive phase to simulate possible remedial pumping schemes.

The primary objectives of the preliminary modeling effort in Phase I are to identify areas of high uncertainty and critical conceptual or data gaps. In Phase III the groundwater flow model will be revised and updated with additional field data and information. This makes the preliminary model the first stage in achieving the ultimate objective of constructing a model that can be used to assess the feasibility of remedial options. The primary purpose of the model study will be to evaluate the feasibility of a remediation pumping system; and, if this form of remediation is feasible, what pumping scenario should capture the contaminant plume.

1.2 DATA COLLECTION

Over the course of three months, geologic data and information were identified and collected for approximately 130 water-supply and monitor wells. Information such as drillers' logs, water elevations, well pumpage data, pump test data, specific-capacity test data, and geophysical logs were collected. Most of the information pertaining to each well was for the entire history of that well. However, geophysical logs were identified and collected only for the following wells:

- 17th St. Redrill.
- DHS monitor wells.
- 9th and Perris well.
- 9th and Garner well.
- Encanto Park monitor wells.
- 10th and J well.

(The last four are located within 2000 ft of each other).

During the data collection period, meetings were arranged with the City of San Bernardino Water Department, Riverside Highland Water Company, City of Colton Water Department, San Bernardino Valley Municipal Water District, U.S. Geological Survey, and University of California at Riverside for the purpose of locating data (particularly well information) that would be useful for the model. Well information was collected from these 6 water agencies and from 19 additional water agencies not listed above. Also, second-hand well information was acquired for approximately 15 additional wells through private consulting reports, M.S. theses, and U.S. Geological Survey Open-file reports.

1.3 MODEL STAGES

Six basic model stages using project flow model exist from development of the conceptual model through the continued model study of Phase III. The six model stages are listed below:

- Development of conceptual model.
- Preparation of input data for preliminary model.
- Model calibration:
  - Calibration of steady-state model.
  - Calibration of transient model.
- Verification of the model.
- Predictive stage using various remediation pumping schemes.
- Sensitivity analyses.

To date, the conceptual model has been developed based on existing data. Preparation of input data for the preliminary groundwater flow model has been accomplished; and, calibration of the preliminary steady-state model is nearly complete. Development of the conceptual model consisted of grouping together the existing hydrogeologic and geologic data available for the model area and constructing geologic cross-sections and structure maps from these data. As a result of these procedures, the hydrogeologic and geologic system was formulated into a conceptual model. After the conceptual model was developed, a steady-state model was developed to evaluate the distribution of groundwater elevations (heads). The head distribution will be used as the initial conditions during later, transient simulations. Once the steady-state model was designed, the geologic and hydrologic input data were prepared into a compatible format for the project flow model to read.

The input data and boundary conditions were used in the project flow model to generate a solution for the heads at each grid node. However, for the results to be considered representative of actual flow conditions, it is necessary to match the computed heads with heads measured at a number of wells in the field. Calibration consists of adjusting the input data and boundary conditions until computed heads match the field values. The combination of parameters and conditions that produce head match is typically achieved through a trial and error process.

The project flow model is being calibrated from 1982 to 1986 in a steady-state condition using a set of input data and boundary conditions. This steady-state calibration period is being used because the heads did not change significantly over this time period. The input data and boundary conditions consist of the following parameters:

- Transmissivities
- Hydraulic conductivities
- Well pumpage
- Stream recharge
- Top and bottom elevations of hydrologic layers
- Leakage values for confining clay layer
- Initial water elevations

These values will be described in more detail in Section 1.5.

During the transient phase, the combination of input data, boundary conditions, and computed 1986 heads calculated from the steady-state phase will be used to simulate groundwater flow conditions from 1986 to 1990. It is possible that some of the input data and boundary conditions may need modification during this phase.

Various combinations of parameters and conditions will reproduce field measured head values at certain nodes in the model grid. It is commonly accepted that the combination of parameters and conditions found by trial and error in the steady-state phase is not unique. A verification analysis will be performed, after the transient phase is complete, to demonstrate that the combination of parameters and conditions found by trial and error are capable of simulating some historical hydrologic event for which field data are available. For example, one might attempt to simulate drawdowns during a pump test or water level declines during a drought. Generally, some additional refinement of parameters will be necessary during verification (Wang and Anderson, 1982). After the model has been calibrated and verified, it is ready to be used for the predictive phase.

The ultimate goal of the model study will be to apply the project flow model in a predictive phase for simulating several remediation pumping schemes to capture the contaminant plume. The project flow model will be used to evaluate the number, location, and pumping rates of the anticipated extraction wells. Approximately 10 to 20 extraction wells will be placed at different locations near or within the plume for predictive simulations using the project flow model. These wells may also include existing wells in the area. Several predictive scenarios will be simulated with various pumping rates and from different hydrologic zones in order to optimize the proposed extraction system.

1.4 REVIEW OF CONCEPTUAL MODEL

The following section briefly discusses the conceptual hydrogeologic model for the project. Greater detail can be found in a Conceptual Model Technical Memorandum dated January 2, 1991.

1.4.1 STUDY AREA AND MODEL AREA

A study area for the Newmark Wellfield (Figure 2) slightly larger than the model area was selected to simulate accurate conditions along the model area boundaries. The model area was designed to minimize the effects of groundwater flow and pumping conditions through various natural physical boundaries such as faults, streams, and impermeable bedrock features.

The study area covers approximately 72 square miles and extends from the San Bernardino Mountains on the north to just south of Interstate 10 on the south. The eastern boundary coincides with Tippecanoe Street (just east of Waterman Avenue). The western boundary is just west of Riverside Avenue (Figure 1).

The model area is within the study area and covers approximately 45 square miles. The eastern and western boundaries of the model area follow those of the study area. The San Andreas fault borders the northeastern end of the model area. The San Jacinto fault borders the southwestern end. These faults were selected as the northeastern and southwestern boundaries because they form groundwater barriers for the northeastern and southwestern ends of the model area (Dutcher and Garrett, 1963). The portions of the study area northeast of the San Andreas fault and southwest of the San Jacinto fault are considered inactive areas and are not included in the model area.

The eastern boundary, which coincides for both the study and model area, is just east of the north/south trending East Twin Creek. The eastern boundary was chosen for this particular area because East Twin Creek forms a hydrologic barrier for inflowing water to the model area from the east.

The western boundary, which also coincides for both the study and model area, was a more difficult selection, because it does not follow any hydrologic barriers. Thus, water flows freely across this boundary at varying rates. However, the western boundary is located approximately 12,000 feet west of an impermeable bedrock feature (Shandin Hills) where groundwater flowing from the north divides and flows along the east and west sides of Shandin Hills. Therefore, the western boundary was chosen a sufficient distance to the west of Shandin Hills in order to minimize impermeable boundary effects on the groundwater flow simulation around the western edge of Shandin Hills.

1.4.2 GEOLOGY

The model area lies between two northwest-trending faults (San Andreas and San Jacinto faults) forming the San Bernardino Valley. The San Bernardino Valley is filled with water-bearing alluvial deposits that were originally derived from the San Gabriel Mountains to the northwest and the San Bernardino Mountains to the northeast. The valley floor underlying the alluvium consists of impermeable basement complex rocks (bedrock). The bedrock is composed of pre-Tertiary igneous and metamorphic rocks. The San Gabriel Mountains, San Bernardino Mountains, and the various hills that are scattered throughout the study area are also composed of bedrock material. The alluvium consists of boulders, gravel, sand, silt, and clay that are of late Tertiary and Quaternary age (Dutcher and Garrett, 1963).

This region between the two faults consists of a series of stair-stepping faults with bedrock hills protruding above the alluvium. The Loma Linda fault is located approximately one mile north of the San Jacinto Fault and extends across the model area in a northwest/southeast trend. Fault K is located approximately one and half miles south of the San Andreas fault and trends northwest/southeast. Fault K extends from the western boundary to directly north of Shandin Hills in the model area. The confluent alluvial fans that fill the San Bernardino Valley formed at the base of mountains where erosion provided a supply of sediment.

The sediments become thicker toward the center of the valley (Domenico and Schwartz, 1990). They occur as channelized or sheet deposits depending on the confining features present in the alluvial valley. Thin layers of coarse sediments, such as gravel and sand, were deposited at the base of mountains where the greater topographical relief resulted in increased flow velocities. The sediments become finer and thicker towards the valley where the topography is flatter as a result of a slower flow velocity.

The alluvium in the San Bernardino Valley area varies considerably in thickness with maximum alluvial thickness occurring adjacent to the northeast side of the San Jacinto fault (Fife et al., 1976; Hardt and Hutchinson, 1980). Within the study area, the alluvium increases in thickness from 400 feet at the Newmark Wellfield near the base of the San Bernardino Mountains to at least 2100 feet at the Loma Linda/San Jacinto fault zone near the center of the San Bernardino Valley (Youngs et al., 1981). The alluvium thicknesses are based on interpretation of drillers' logs. The northern portion of the study area, just south of the San Bernardino Mountains, consists predominantly of sand, gravel and boulders with little or no clay. However, in the central and southern portions of the model area, the presence of clay increases. Interpretation of the Waterman Avenue well driller's log provides the northern boundary for the presence of clay in the valley. The number of clay lenses and the thickness of the clay lenses increase along a north/south trend. Variations in thicknesses of the middle confining clay unit (according to well locations) are listed in Table 1.

1.4.3 HYDROGEOLOGY

The regional groundwater flow direction is generally toward the south. Locally, the groundwater flow direction is southeast around the west side of Shandin Hills and southwest on the east side of the study area. Once groundwater passes Shandin Hills, the flows converge and continue south toward the Santa Ana River.

Appendix J

Table 1

THICKNESSES AND LEAKANCE
VALUES FOR MIDDLE
CONFINING CLAY UNIT

Well Name/Description	State Well Locations	Map No. on Figure 14	Top Elevation (feet)	Bottom Elevation (feet)	Thickness (feet)	Leakance [a] (ft/day)/ft x 10^{-7}
San Bernardino Ice Delivery #2	1S4W09B02	419	739	683	56	5.06
Mt. Vernon Water Company	1N4W24A01S	22	823	783	40	7.08
City of San Bernardino, Antil #2	1S4W02K01	120	779	649	130	2.18
City of San Bernardino, Antil #2	4S4W02K01	121	780	586	194	1.46
City of San Bernardino, Antil #4	1S4W02K03S	39	678	632	46	6.16
City of San Bernardino, Antil #5	1S4W02K02S	38	764	674	90	3.15
City of San Bernardino, Antil #6	1S4W02K08S	40	792	648	144	1.97
City of San Bernardino, Hanford #2	1S4W10F05	122	592	500	92	3.08
City of San Bernardino, A. Ree	1S4W11K01	123	702	616	86	3.29
City of San Bernardino, Mill & "D" Street	1S4W10N06	124	584	504	80	3.54
City of San Bernardino, South "G" Street	1S4W09J01S	125	650	556	94	3.01
City of San Bernardino, 16th Street	1N4W34G03S	28	815	625	190	1.49
City of San Bernardino, 17th Street	1N4W34G01S	27	873	673	200	1.42
City of San Bernardino, 19th Street #1	1N4W43D03S	24	873	758	115	2.46
City of San Bernardino, 19th Street #2	1N4W32D04S	25	875	735	140	2.02
City of San Bernardino, 23rd Street	1N4W27N01S	18	920	834	86	3.30
City of San Bernardino, North "E" Street	1N4W27M01S	16	963	870	93	3.05
City of San Bernardino, 27th Street	1N4W27M02S	17	925	895	30	9.45
City of San Bernardino, 30th Street & Mt. View (Marshall)	1N4W27G01S	15	NC	NC	NC	NC
City of San Bernardino,24st Street & Mt. View	1N4W27B	14	NC	NC	NC	NC
City of San Bernardino, 7th Street	1S4W03J	46	869	586	282	4.00

Appendix J

Table 1 (Cont'd.)

THICKNESSES AND LEAKANCE
VALUES FOR MIDDLE
CONFINING CLAY UNIT

Well Name/Description	State Well Locations	Map No. on Figure 14	Top Elevation (feet)	Bottom Elevation (feet)	Thickness (feet)	Leakance [a] (ft/day)/ft x 10^{-7}
City of San Bernardino, Gilbert Street	1N4W35M03S	34	913	777	136	2.08
City of San Bernardino, Lynwood	1N4W26G	8	1005	925	80	3.54
City of San Bernardino, Newmark #1	1N4W16E01S	101	NC	NC	NC	NC
City of San Bernardino, Newmark #2	1N4W16E	100	NC	NC	NC	NC
City of San Bernardino, Newmark #2	4N4W16E03S	102	NC	NC	NC	NC
City of San Bernardino, Newmark #4	1N4W16E	3	NC	NC	NC	NC
City of San Bernardino, Perris Hill #5	1N4W26P02	426	963	909	54	5.25
City of San Bernardino, Waterman Avenue	1N4W27A01S	12	4002	947	55	5.15
City of San Bernardino, Baseline	1N4W32N	26	976	916	60	4.72
City of San Bernardino, Darby	1N4W29E01S	19	1016	983	33	8 59
City of San Bernardino, Colima	1N4W29F01S	20	949	864	85	3.33
Nevada California Power Company #2	1S4W21Q2	427	779	699	80	3.54
Riverside Water Company., Vaugh #1	1S4W21Q2	428	665	576	89	3.19

[a] Vertical conductivity of 10^{-7} cm/sec or 2.83 x 10^{-4} ft/day was used.
NC = No Confining Clay Unit

The groundwater in the study area originates from surface water runoff in the San Bernardino Mountains. Surface water flows into the study area across the San Andreas fault through the outlets of Devil Canyon, Badger Canyon and Waterman Canyon (Hardt and Hutchinson, 1980). Once surface water has passed the base of the San Bernardino Mountains, it flows into percolation basins located downslope of each canyon outlet. Most of the surface water percolates through the alluvial deposits and serves to enhance groundwater recharge. The remainder of the water flows into nearby streams where it is lost to the atmosphere through evapotranspiration or flow out of the basin. Streams and rivers may act as natural recharge or discharge points for groundwater and surface water depending on the position of the water table relative to the water level in the streams.

The streams located in the study area contain intermittent flow depending on the season of the year. During the wet winter and spring months, the water that fills the streams for short durations percolates down to the groundwater. During the dry summer months, the streams contain no water and groundwater probably flows towards the streams and discharges to the atmosphere through evapotranspiration where the water table is within 10 feet of the ground surface. The recharge/discharge relationship of the streams to the aquifers will be discussed in more detail in Section 1.5.6.

The alluvium within the model area has been divided into two aquifer systems, separated by a zone consisting predominantly of discontinuous clay lenses. Through interpretation of the drillers' logs, the portion of the study area north of Shandin Hills probably contains few and scattered thin clay lenses; therefore, the aquifer in this area is considered to be an unconfined aquifer (or water-table aquifer). South of Shandin Hills the alluvium becomes interfingered with many clay lenses. In this area, the alluvium divides into two major aquifers. The upper aquifer remains an unconfined aquifer; but, the lower aquifer is confined by the overlying zone of interfingered clay lenses. The identification of two aquifers to the south of Shandin Hills was based mainly on the recorded water levels and the placement of the well perforations during the installation of the wells. The thicknesses and elevations of the middle confining clay unit for each well are listed in Table 1. Hardt and Hutchinson (1980) also support the concept of one unconfined aquifer to the north of Shandin Hills and two aquifers to the south of Shandin Hills, with the lower aquifer being confined. The conceptual model will be discussed further in Section 1.5.1.

1.4.4 GRID SYSTEM

A grid system with constant grid spacing was constructed for the preliminary steady-state model. The grid system consists of 3360 square cells (42 columns and 80 rows). Each cell measures 820.25 feet in both the x- and y-directions. The grid system for the study and model area is displayed in Figure 2.

1.5 PREPARATION OF THE STEADY-STATE MODEL

This section will discuss the preparation of the input data for simulation of the preliminary steady-state model. The following input data were arranged into input files that were read by the project flow model:

- Hydrogeologic layers
- Boundary conditions
- Initial head conditions
- Percolation basins and ponds
- Hydraulic conductivity and/or transmissivity values
- Well pumpage
- Vertical leakance values

The input files have undergone changes during the calibration process. The calibration process has consisted of seven major grouped runs containing two to five individual modifications. A total of 29 calibration runs have been performed. The results of each calibration run were saved to individual output files. The following sections will describe in detail the preparation and nomenclature of the input files. The nomenclature for the input files is arranged in the following format:

- The filename for the input file contains a rootname and an extension. For example, the filename *RUN.BCF* contains a rootname of *RUN* and an extension of *BCF.*

- The rootname for every input file identifies run number, modification letter, and date (month and day) the file was produced. For example, an output file produced from the first run, the first modification, and on April 11 would have the filename *1A0411.OUT.* For the purposes of this section, the rootname *RUN* will represent a generalized run, modification and date.

- The extensions for all filenames are abbreviations of the input packages used in the project flow model (*BCF, BAS, WEL,* etc.).

- The abbreviated extensions for the input packages used in the project flow model consist of *BAS* for Basic, *BCF* for Block-Centered Flow, *OC* for Output Control, *SIP* for Strongly-Implicit Procedure, *STR* for Streamflow Routing, *WEL* for Well, *RIV* for River, and *GHB* for General-head Boundary.

1.5.1 HYDROGEOLOGIC LAYERS

The model area consists of igneous and metamorphic basement rock that was downdropped between the San Andreas and San Jacinto faults. The basin is filled with alluvial deposits which spread around the bedrock hills and reach a thickness of at least 2100 feet in the southern portion of the model area northeast of the San Jacinto fault (Hardt and Hutchinson, 1980). From here, the basin deposits become progressively thinner towards the northwest and north near the San Bernardino Mountains. Figure 3 shows interpreted thickness of the alluvium for the model area. Figure 3 was modified from Hardt and Hutchinson (1980) using additional well information. Figure 4 depicts the interpreted surface of the bedrock for the model area.

Several cross-sections were constructed from a detailed analysis of approximately 100 drillers' logs. Interfingering clay lenses evident in the individual drillers' logs were grouped together into one middle clay unit that acts as a confining layer for the lower aquifer. Table 1 shows the top and bottom elevations of the middle confining clay unit chosen from each drillers' log. The detailed cross-sections were then compiled into two conceptual cross-sections. Figure 5 shows the locations of the conceptual cross-sections. Figure 6a represents a north/south cross-section and Figure 6b represents an east/west cross-section.

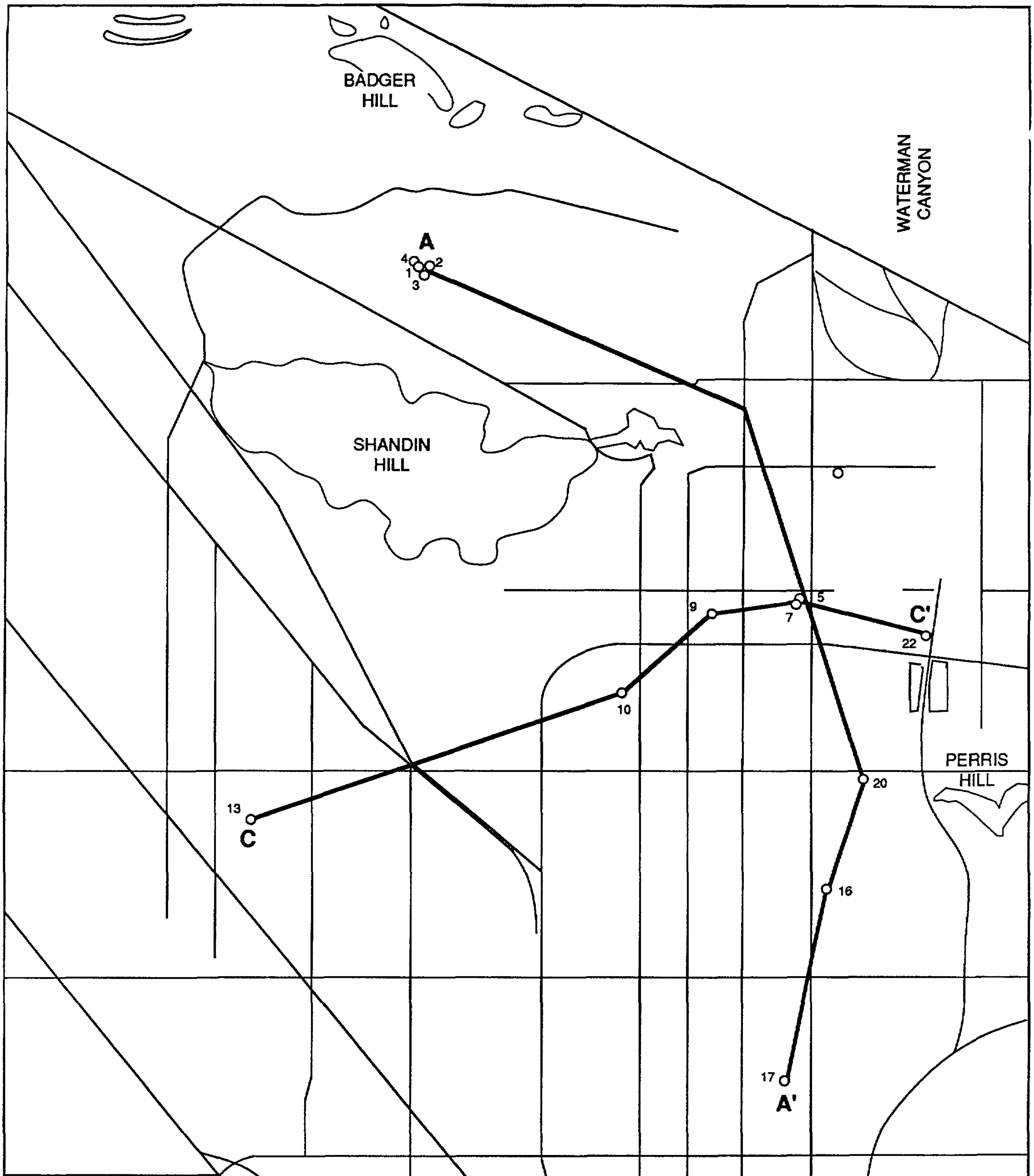

Figure 5
Cross Section Location Map

URS #159 4/91

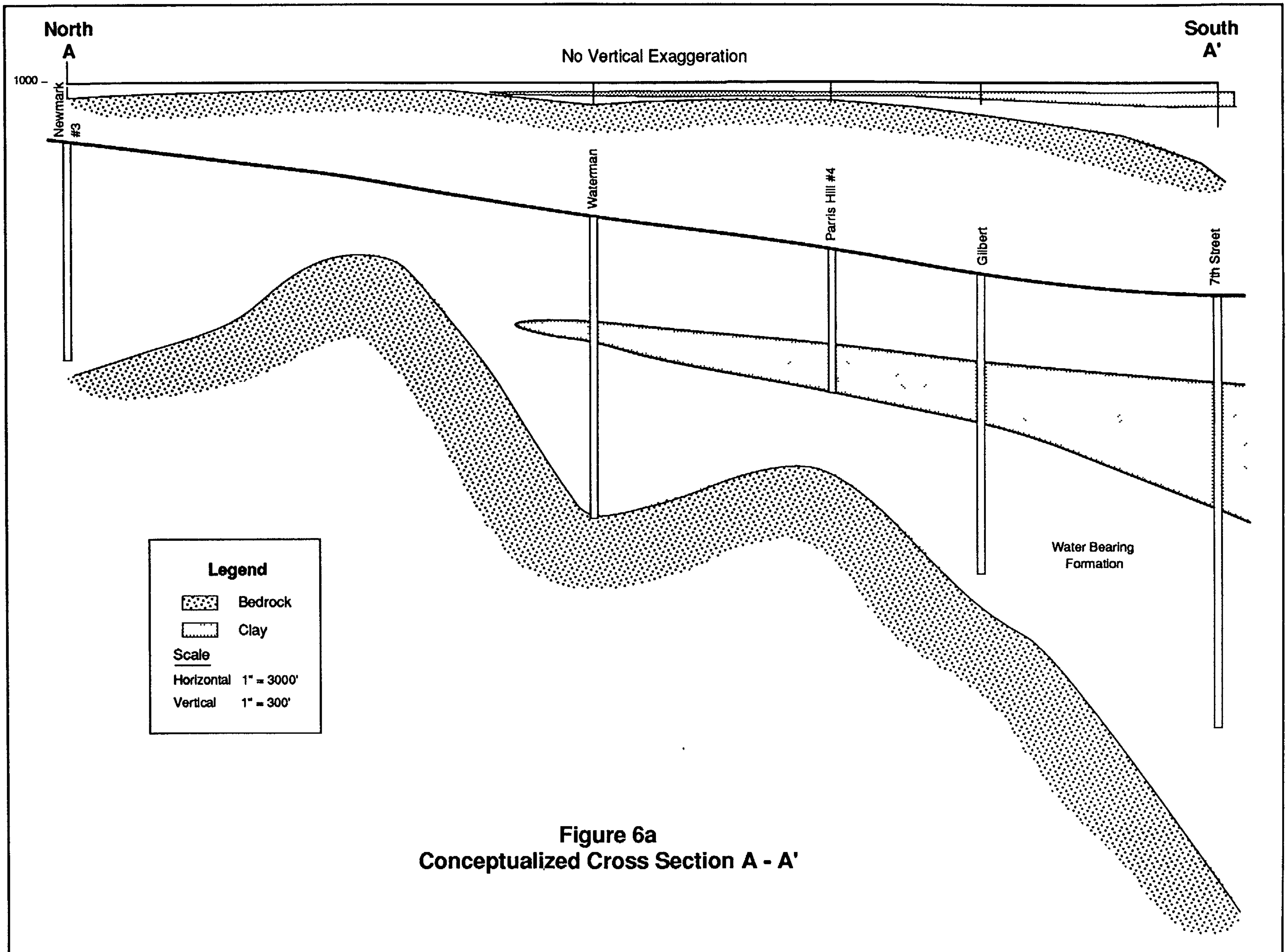

Figure 6a
Conceptualized Cross Section A - A'

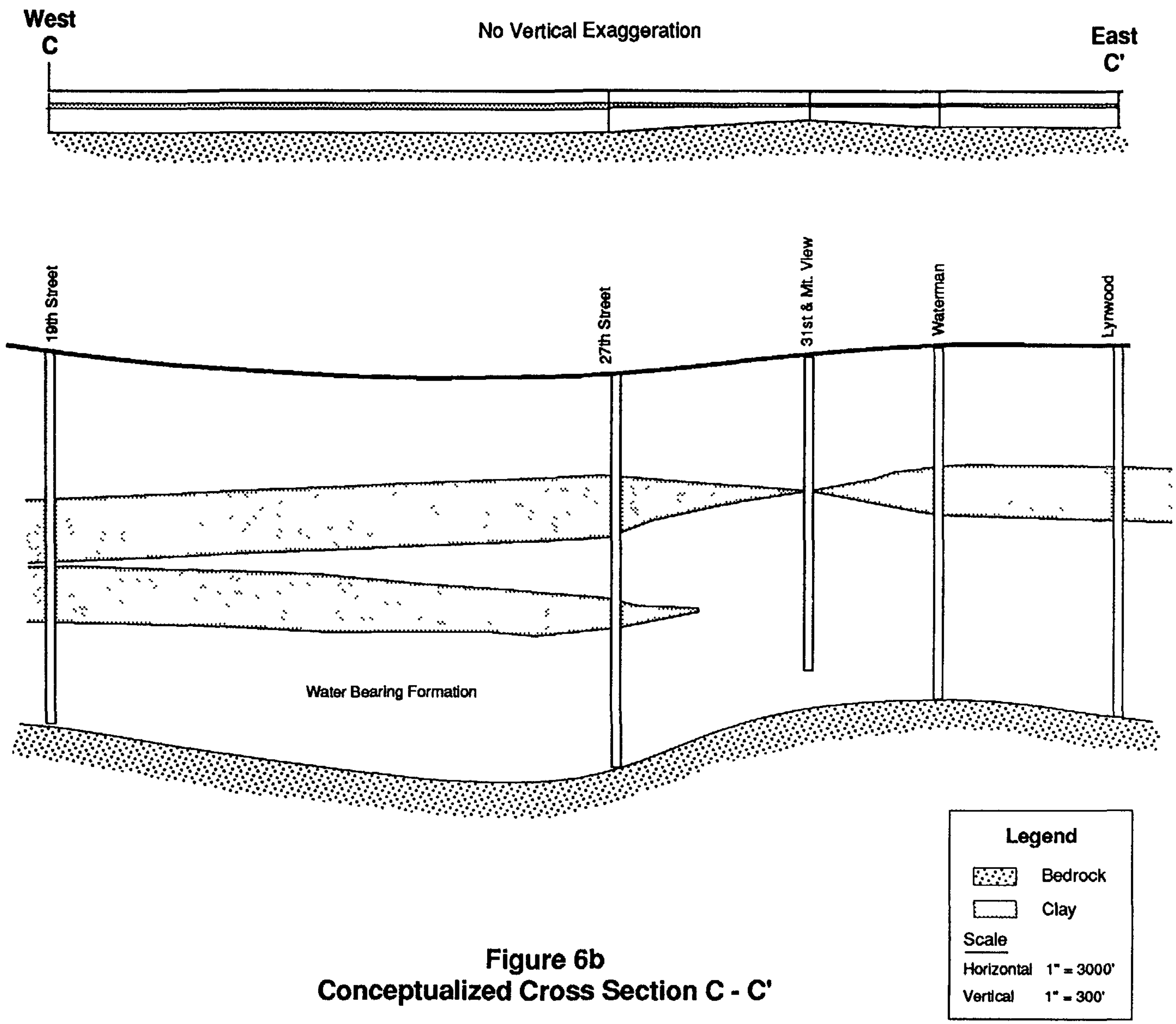

Figure 6b
Conceptualized Cross Section C - C'

URS #119 4/91

After further analysis of the cross-sections, the model area was divided into two major aquifers. The area north of Shandin Hills consists of one unconfined aquifer. The area just south of Shandin Hills is comprised of two aquifers: the upper aquifer, an extension of the unconfined aquifer north of Shandin Hills and the lower aquifer, a separate, confined aquifer. However, for modeling purposes the aquifer north of Shandin Hills was separated into two aquifers by extending the middle confining clay unit through this area at a one-foot thickness.

To further define the aquifer system for model representation, two structure maps were constructed for the middle confining clay unit using the elevations listed in Table 1. Figure 7 shows the elevations for the top surface of the middle confining clay unit, and Figure 8 shows the elevations for the bottom surface of the middle confining clay unit.

The middle confining clay unit is predominantly clay, but includes varying amounts of sand and gravel. The unit is at least 300 feet thick in the central part of the study area near the 7th Street well and thins towards the northern parts of the study area. The top surface of the middle confining clay unit ranges from 1016 feet above sea level at the Darby Well just south of the southwest corner of Shandin Hills to approximately 580 feet above sea level in the central part of the model area near Warm Creek.

The middle confining clay unit was not modeled as a separate hydrologic layer but rather its thickness was embedded in the vertical leakance values for the overlying unconfined aquifer (layer 1). The vertical leakance values for the middle confining clay unit will be discussed in more detail in Section 1.5.7. The upper model layer (layer 1) is above the middle confining clay unit, and the lower model layer (layer 2) is below the middle confining clay unit. The greatest thickness of water-bearing deposits is in layer 2. For representation of the hydrogeologic layers in the model, the bottom elevations of layer 1 and top elevations of layer 2 are identified and placed in the Block-centered Flow (BCF) input file. The bottom elevations for layer 1 will correspond to the top elevations of the middle confining clay unit displayed in Figure 7 and the top elevations for layer 2 will correspond to the bottom elevations of the middle confining clay unit displayed in Figure 8. Since the designated bottom of layer 1 and top of layer 2 do not coincide, the project flow model recognizes the break between the layers as a middle confining clay unit. The actual thickness of the middle confining clay unit is figured into the vertical leakance values, which will be described in Section 1.5.7.

1.5.2 BOUNDARY CONDITIONS

The boundary conditions for the model area were defined by the geometry of the model area, by the groundwater/surface water flow conditions, and by the geologic structures (faults, subsurface groundwater barriers, and impermeable bedrock features) in the area. Several boundary condition subroutines that are available in the project flow model were used to represent the actual boundary conditions within the model area. Actual boundary conditions for the model area were represented in the project flow model as no-flow, constant-head, and head-dependent conditions. The boundary conditions are assigned to the individual cells of the model, both for layers 1 and 2.

No-flow Conditions

No-flow conditions were simulated in the model for several impermeable areas that include bedrock hills, mountains, and fault zones. Shandin Hills, Badger Hill, Wiggins Hill, and Perris Hill are bedrock hills that impede groundwater flow within the model area. The San Andreas and San Jacinto faults form no-flow boundaries that border the northeastern and southwestern boundaries of the model area. The northwest portion of the Loma Linda fault and the groundwater barrier extension shown in Figure 9 both form partial groundwater barriers (Dutcher and Garrett, 1963).

It was concluded from water level data, Fault K possibly extends across the model area following the same northwest trend. Water level measurements have shown that the heads on the north side of the fault zone are 50 to 80 feet higher than those on the south side. Additional aquifer test data indicate that this area forms at least a partial groundwater barrier.

Figure 9 displays the no-flow cells (impermeable areas) and the partial-flow cells (partial groundwater barriers). The Basic (BAS) input file (*RUN.BAS*) contains the essential information for the no-flow cells.

Partial-flow cells were developed by assigning low hydraulic conductivity/transmissivity values to these cells. Information pertinent to the partial-flow cells are flagged in the Basic (*RUN.BAS*) and Block-centered Flow (*RUN.BCF*) input files. The hydraulic conductivity/transmissivity values for the upper verses lower aquifers will be discussed in Section 1.5.5.

Constant-head Conditions

Constant-head conditions were used along the western and eastern boundaries of the model area between the San Andreas and San Jacinto faults to simulate flow into and out of the model area. For the lower aquifer, constant-head conditions were used for all the cells along these western and eastern boundaries except where Perris Hill bedrock is exposed. For the upper aquifer constant-head conditions were used for all the cells along these western and eastern boundaries except at the intersections of the streams, faults or Perris Hill.

The groundwater elevation contours show that groundwater flows into and out of the alluvial basin across the eastern and western boundaries. In order to simulate water entering and leaving the model area through these cells, constant heads were set for the cells along these boundaries.

Figure 9 displays the constant-head cells along the western and eastern boundaries for both the upper and lower aquifers. Information pertinent to the constant-head cells is located in the Basic input file (*RUN.BAS*). The initial heads (described in Section 1.5.3) that are set for the constant-head cells of the upper and lower aquifers remained unchanged throughout the simulation of the model.

Head-dependent Conditions

Head-dependent conditions were simulated using the General-head Boundary package in several calibration runs in place of the constant-head conditions for the eastern and western boundaries. The Streamflow routing package was replaced with the River and the General-head Boundary packages so that inflowing and outflowing groundwater values at the upslope cells of the streams could be varied. When the Streamflow routing (STR) package was replaced with the River (RIV) package, head-dependent conditions were also assigned to the most upgradient and downgradient positions of the streams where they enter or leave the model area. Furthermore, head-dependent conditions were assigned to the upper aquifer cells since the streams influence only the upper aquifer.

Head-dependent conditions were assigned to the most upgradient or downgradient positions of the following streams and canyons which are displayed in Figure 9:

- The upper cell of Devil Canyon where it intersects the San Andreas fault
- The upper two cells of Waterman Canyon where they intersect the San Andreas fault
- The upper eleven cells of Lytle Creek Wash located on the western boundary of the model area
- The upper cell of East Twin Creek located on the eastern boundary of the model area
- The upper five cells of the Santa Ana River located on the eastern boundary of the model area
- The upper cell of San Timoteo Wash located on the eastern boundary of the model area
- The lower six cells of the Santa Ana River where it crosses the San Jacinto fault

Head-dependent conditions allow for flow to enter or leave a cell i,j,k from an external source. The location of each cell i,j,k is designated by the row (i), column (j), and layer (k). This flow, $Q_{bi,j,k}$, is proportional to the difference between the head in the cell, $h_{i,j,k}$, and the head assigned to the external source, $h_{bi,j,k}$. Thus, a linear relationship between flow into the cell and head in the cell is established,

$$Q_{bi,j,k} = C_{bi,j,k} (h_{i,j,k} - h_{bi,j,k}) \qquad (1)$$

where, $C_{i,j,k}$ is the conductance between the external source and cell i,j,k (McDonald and Harbaugh, 1988). Conductance equals the horizontal hydraulic conductivity times the cross-sectional area of the external source.

Several input parameters were needed to simulate the flow across the head-dependent cells:

- Heads for the external source
- Cross-sectional area for the external source
- Horizontal hydraulic conductivity of the external source area

The location of each head-dependent cell (layer, row and column) and the assigned input parameters listed above are contained in the General-head Boundary (GHB) input file (*RUN.GHB*).

Flow values across each head-dependent cell for the upper and lower cells of these streams were calibrated with the 1982 streamflow data for the corresponding gaging station locations. Table 2 lists the streamflow data that were used in this calibration. Figure 10 illustrates the locations of the gaging stations.

1.5.3 INITIAL HEAD CONDITIONS

The project flow model is calibrated from 1982 to 1986 in a steady-state condition. This period was chosen to run the steady-state phase of the model because groundwater elevations and the total inflow and outflow of water from the study area did not vary significantly during this time period (Hardt and Freckleton, 1987 and Duell and Schroeder, 1989).

January 1982 water elevations were used for the initial head conditions. These water elevations were obtained from Hardt and Freckleton (1987). Figure 11 displays the January 1982 initial water elevations for the upper aquifer. Figure 12 displays the January 1982 initial water elevations for the lower aquifer. The initial water elevations for the upper and lower aquifers are contained in the Basic input file (*RUN.BAS*).

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Table 2

STREAMFLOW DATA FOR THE SAN BERNARDINO AREA (1982)

Station Name	Station Number	Streamflow (Cu. ft/day)	Map No. on Figure 10
		Inflow	
Santa Ana River near Mentone [a]	110510501	7,350,800	515
Mill Creek near Yucaipa [a]	11054001	3,391,9000	540
Plunge Creek near East Highlands [a]	11055501	825,9000	555
City Creek near Highland	11055800	821,100	558
San Timoteo Creek near Redlands	11058000	240,400	570
East Twin Creek near Arrowhead Springs	11057000	549,00	585
Waterman Canyon Creek near Arrowhead Springs	11058600	266,2000	586
Lytle Creek near Fontana [a]	11062001	4,612,200	620
Lone Pine Creek near Keenbrook	11063651	905,900	635
Devil Canjon Creek near San Bernardino[a]	11063680	382,300	630.8
Cajon Creek near Keenbrook	11063000	729,700	630
		Outlfow	
Santa Ana River at E Street	11059300	7,241,400	593
Santa Ana River near San Bernardino	11056200	---	562
Lytle Creek at Colton	11065000	359,200	650

[a] Combined flow, includes diversions.
Source: Hardt and Freckleton (1987).

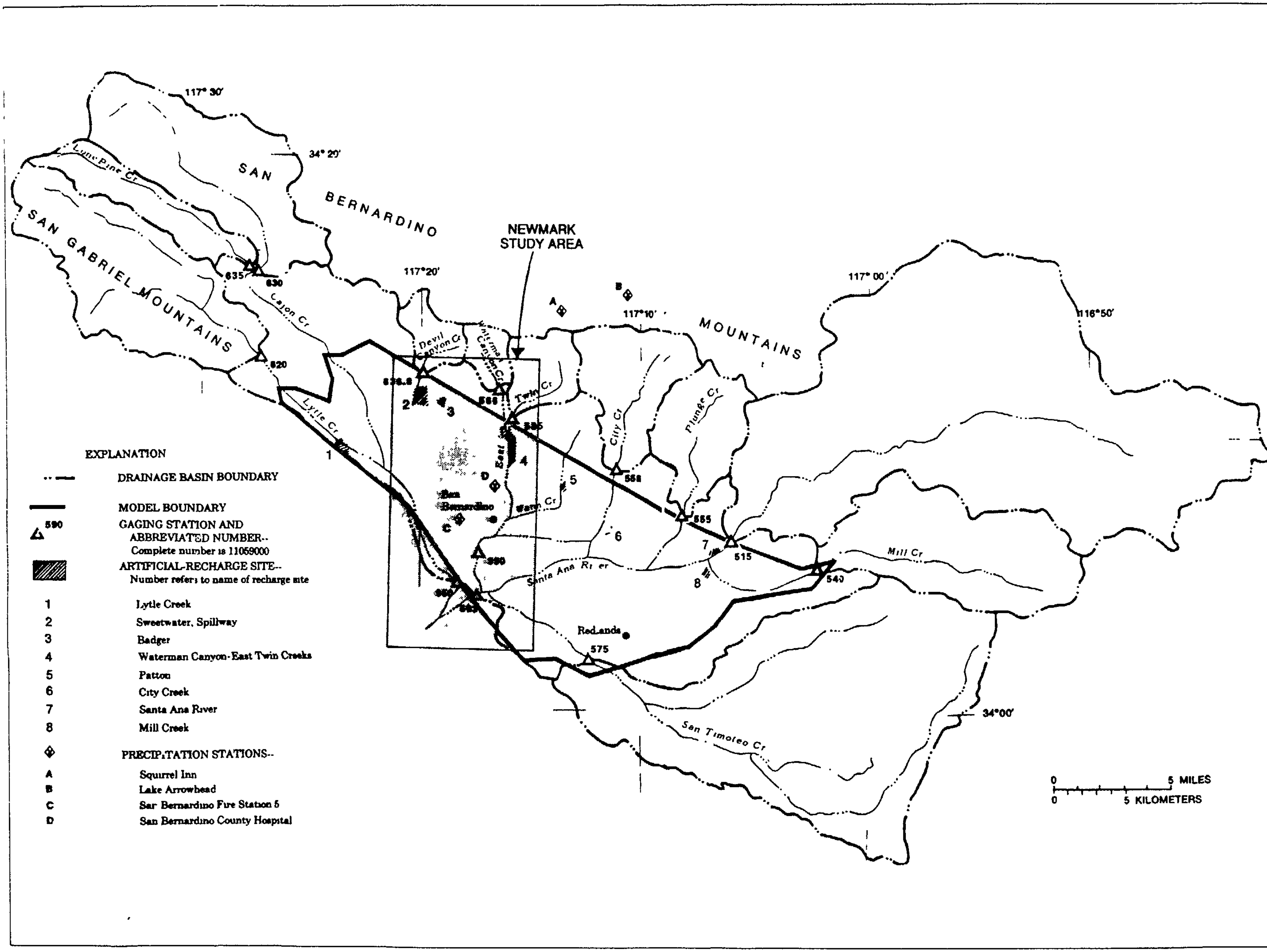

FIGURE 10
Stream Gage Locations
(Source: Hardt & Freckleton 1987)

NEWMARK RI/FS
PRELIMINARY STEADY-STATE
MODEL TECHNICAL MEMORANDUM

URS CONSULTANTS
2710 GATEWAY OAKS DR.
SUITE 250 NORTH
SACRAMENTO, CA 95834

1.5.4 SURFACE-WATER AND GROUNDWATER INTERACTION

Surface water enters the model area through various streams flowing from the north out of the San Bernardino Mountains and from the east and west sides of the model area. Most of the surface water enters the model area through Devil Canyon and Waterman Canyon-East Twin Creek. These canyons collect runoff water from the San Bernardino Mountains. The remainder of the surface water enters the east side of the model area through Warm Creek, Santa Ana River and San Timoteo Wash, and the west side of the model area through Lytle Creek Wash. Some surface water leaves the model area intermittently through the Santa Ana River where it crosses the San Jacinto fault to the south (Hardt and Hutchinson, 1980).

Groundwater movement in the model area follows the surface-drainage pattern. Groundwater generally moves southward in the model area, except in the Lytle Creek area where it moves southeastward and converges toward a common line of discharge at the San Jacinto fault beneath the Santa Ana River. The potentiometric head is above the confining beds in this area, and because the San Jacinto fault restricts groundwater flow, groundwater is forced through and around the clay beds into the overlying strata and onto the land surface. Consequently, significant components of vertical flow are created in the groundwater flow regimen.

Surface water is piped into the model area and released at three recharge facilities (percolation basins) at the base of the San Bernardino Mountains predominantly during the dry, summer months (Figure 10). Sweetwater spillway lies just south of Devil Canyon. The Badger recharge area is located to the west of Badger Hill. The Waterman Canyon-East Twin Creek facility contains percolation basins just south of Waterman Canyon.

Surface-water inflow and outflow for the model area has been measured at selected gaging stations (Figure 10). The data show, except during high flows caused by infrequent flooding, the inflows are much larger than the outflows. Thus, it is concluded that most of the surface flow that enters the valley percolates into the aquifer (Hardt and Hutchinson, 1980).

Generally, the flow from small streams (Devil Canyon, Waterman Canyon-East Twin Creek, San Timoteo Wash, and Warm Creek) is recharged locally into the aquifer within a few miles of the mountain front. Therefore, the recharge areas for Devil Canyon and Waterman Canyon-East Twin Creek only occur at the percolation basins. South of these basins the streams function as subsurface discharge areas for groundwater in the model area. In the subsurface discharge areas of the streams, groundwater flows towards the permeable, subsurface streambeds. The groundwater is released upward to the atmosphere through evapotranspiration where groundwater is within 10 feet of the ground surface. The recharge areas for Warm Creek and San Timoteo Wash are located outside Newmark model area to the northeast. Consequently, the portions of the Warm Creek and San Timoteo Wash located within the model area function as discharge areas for groundwater flow.

Large flow rates are transmitted by the larger streams (Santa Ana River and Lytle Creek) in a short time during flood periods. Surface-water and groundwater discharge of these flood flows out of the model area occurs primarily where the Santa Ana River crosses the San Jacinto fault. Initially, the Streamflow routing package in the project flow model was used to simulate the effects of flow between the surface-water features and the groundwater system. Later, in *RUN 7*, the Streamflow routing package was replaced with the General-head Boundary and River packages. The General-head Boundary package of the project flow model was used to simulate the groundwater flow into and out of the model area across the upgradient cells of the streams. The River package of the project flow model was used to simulate the effects of flow between the surface-water features and the groundwater system. The river package was set up so that surface water recharged the groundwater at all isolated percolation basins and percolation basins connected with the upgradient positions of the streams (Devil Canyon and Waterman Canyon-East Twin Creek). The remainder of the streams were set up as groundwater discharge areas.

Flow between the stream and the groundwater system is characterized by:

$$QRIV = CRIV\ (HRIV - h_{i,j,k}) \qquad (2)$$

where, QRIV is the flow between the stream and the aquifer with a positive value if it is directed into the aquifer; HRIV is the head in the stream; CRIV is the hydraulic conductance of the stream-aquifer interconnection; and $h_{i,j,k}$ is the head at the node in the cell underlying the stream reach. The term for the idealized streambed conductance (CRIV) as it crosses an individual cell is further defined by:

$$CRIV = (K\ L\ W)/M \qquad (3)$$

where, L is the length of the stream as it crosses the node; W is the stream width; M is the thickness of the streambed layer; and K is the hydraulic conductivity of the streambed material (McDonald and Harbaugh, 1988). These input values are located in the River input file (*RUN.RIV*).

The Streamflow routing input file (*RUN.STR*) requires the same general information for each stream reach, except that the streams are grouped into stream segments and each segment consist of numbered stream reaches. Streams are separated into different segments so that their upgradient or downgradient counterparts may be linked together for relating surface water between the different stream systems.

1.5.5 <u>HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY VALUES</u>

Hydraulic conductivity and transmissivity are two terms which describe the capability of water to flow through a geologic permeable material. Hydraulic conductivity is the quantity of water that will flow through a unit cross-sectional area of a permeable material per unit of time under a unit of hydraulic gradient at a specified temperature. Transmissivity is the rate of waterflow at the prevailing temperature through a vertical strip of aquifer, under a unit hydraulic gradient. In MODFLOW, hydraulic conductivity values were assigned for unconfined aquifers and transmissivity values were assigned for confined aquifers. Hydraulic conductivity values were therefore assigned to the upper, unconfined aquifer and transmissivity values were assigned to the lower, confined aquifer.

Aquifer tests (specific-capacity and pump tests) were used to quantify the hydraulic conductivity and transmissivity values for the model area. Transmissivity was calculated for each well with records of aquifer test data. Transmissivity values representing the total thickness of the water-bearing alluvium were proportioned according to the thicknesses of each model layer. If, however, particular wells were only perforated in either the lower or upper modeling layer, the total transmissivity value calculated from the aquifer test data represented the transmissivity for that specific model layer.

Table 3 lists the total length of screen and screen elevations for each well. Table 4 lists the original and aquifer test data available. Transmissivity was divided by the saturated thickness at each corresponding well location in order to calculate hydraulic conductivity values for the upper aquifer. Similar values were then grouped into transmissivity/hydraulic conductivity areas as displayed in Figure 13. (Note: These values have undergone some changes during model calibration.)

Faults and impermeable bedrock hills were represented as either no-flow areas or with low transmissivity and hydraulic conductivity values. A hydraulic conductivity of 2.83×10^{-8} ft/day (for upper model layer) and a transmissivity of 2.83×10^{-12} ft^2/day (for lower model layer) were used for the San Andreas and San Jacinto faults and the bedrock hills. The hydraulic conductivity values of the alluvium were used in the areas where streams cross the San Andreas and San Jacinto faults for the upper modeling layer. Hydraulic conductivity and transmissivity values of 10.0 ft/day and 400.0 ft^2/day, respectively, were used to represent the northwest portion of the Loma Linda fault and the groundwater barrier that extends south from the Loma Linda fault (Figure 13).

The hydraulic conductivity values for layer 1 (upper aquifer) and transmissivity values for layer 2 (lower aquifer) are contained in the Block-Centered Flow input files (*RUN.BCF*).

1.5.6 WELL PUMPAGE

Well pumpage (ft^3/day) were also simulated in the flow model. Most of the discharge from the groundwater system in the model area is from water-supply wells. This information was obtained from the Western Watermaster via Wesley Danskin of the U.S. Geological Survey. Well pumpage, for each water-supply well active during the modeling period (1982 to 1986) is listed in Table 5. The location of these wells is shown in Figure 14.

Appendix J

Table 3

WELL INFORMATION AND THE RESPECTIVE SCREENED AQUIFERS

Well Name/Description	State Well Location	Map No. on Figure 14	Surface Elev. (ft)	Total Amt of Screen (ft)	Screen Elev. (ft)	Amt. of Screen in Upper Aquifer	Amt. of Screen in Lower Aquifer
City of San Bernardino, Newmark #2	1N4W16E	100	1405	176	1257 to 1165 1153 to 1069	176	0
City of San Bernardino, Newmark #2	4N4W16E03S	102	1408	191	1176 to 1158 1125 to 1103 1077 to 946	191	0
City of San Bernardino, Newmark #4	1N4W16E	2	4414	104	1114 to 1010	104	0
City of San Bernardino, 16th Street	1N4W34G03S	28	1129	190	639 to 449	0	190
City of San Bernardino, 17th Street	1N4W34G01S	27	1142	172	649 to 571 566 to 472	0	172
City of San Bernardino, Leroy	1N4W27A	12	1240	210	790 to 580	0	210
City of San Bernardino, 30th Street & Mt. View (Marshall)	1N4W27M015	15	1227	130	834 to 704	130	0
City of San Bernardino, 24st Street & Mt. View	1N4W27B	14	1233	228	908 to 680	228	0
City of San Bernardino, 27th Street	1N4W27M02S	17	1184	390	941 to 925 894 to 774 742 to 728 707 to 467	150	240
City of San Bernardino, 23rd Street	1N4W27N01S	18	1175	370	821 to 805 747 to 727 681 to 347	0	370
City of San Bernardino, North "E" Street	1N4W27M015	16	1188	296	728 to 432	0	296
City of San Bernardino, 19th Street #1	1N4W32D03S	24	1224	271	1081 to 955 909 to 875 843 to 824 761 to 719 677 to 668 656 to 620 585 to 572	472	99
City of San Bernardino, 19th Street #2	1N4W32D04S	25	1236	225	1051 to 950 950 to 890 890 to 881 626 to 571	170	55
City of San Bernardino, Waterman Avenue	1N4W27A015	12	4245	324	987 to 978 950 to 635	9	245
City of San Bernardino, Gilbert Street	1N4W35M03S	34	1124	183	644 to 521 499 to 439	0	183

Appendix J

Table 3 (Cont'd.)

WELL INFORMATION AND THE RESPECTIVE SCREENED AQUIFERS

Well Name/Description	State Well Location	Map No. on Figure 14	Surface Elev. (ft)	Total Amt of Screen (ft)	Screen Elev. (ft)	Amt. of Screen in Upper Aquifer	Amt. of Screen in Lower Aquifer
City of San Bernardino, 7th Street	1S4W03J	46	1057	355	505 to 227 196 to 119	0	355
City of San Bernardino, Perris Hill #2	1N4W35C01S	29	1152	Total Depth 433	NI	All	---
City of San Bernardino, Perris Hill #2	4N4W35C02S	30	1167	92	1065 to 1019 1011 to 965	92	0
City of San Bernardino, Perris Hill #4	1N4W35C03S	24	1168	132	1038 to 953 924 to 877	132	0
City of San Bernardino, Perris Hill #5	1N4W26P02	426	1172	412	1047 to 1024 1017 to 963 863 to 821	112	0
City of San Bernardino, Lynwood	1N4W26A025	8	1236	86	916 to 901 892 to 652 607 to 576	0	86
City of San Bernardino, Darby	1N4W29E01S	19	1330	152	1090 to 1059 1033 to 1030 964 to 950 937 to 837	34	118
City of San Bernardino, Gardena	1N4W29	21	1262	460	1128 to 1081 1066 to 1013 957 to 927 893 to 862	430	30
City of San Bernardino, Colima	1N4W29F01S	20	1280	124	1040 to 940 862 to 838	100	24
City of San Bernardino, Devil Canyon #1	1N4W08M01S	99	1560	Total Depth 285	NI	All	---
City of San Bernardino, Devil Canyon #2	1N4W07F01S	98	1630	169	1453 to 1338 1324 to 1244 1274 to 1230	169	0
City of San Bernardino, Antil #5	1S4W02K02S	38	1070	124.5	(-180) to (-304)	0	124.5
City of San Bernardino, Antil #6	1S4W02K08S	40	1070	439	654 to 430 234 to 162 147 to 97 55 to (-38)	0	439

Appendix J

Table 3 (Cont'd.)

WELL INFORMATION AND THE RESPECTIVE SCREENED AQUIFERS

Well Name/Description	State Well Location	Map No. on Figure 14	Surface Elev. (ft)	Total Amt of Screen (ft)	Screen Elev. (ft)	Amt. of Screen in Upper Aquifer	Amt. of Screen in Lower Aquifer
City of San Bernardino, Baseline	1N4W32N	26	1190	196	1064 to 1006 966 to 958 928 to 886 878 to 818 722 to 714 650 to 630	66	130
City of Colton, #19	1S4W08F	50	1104	218	647 to 554 457 to 414 357 to 342 260 to 193	0	218
City of Colton, #21	1S4W08F15S	107B	1094	603	842 to 698 656 to 199	144	459
Riverside Highland Water Company, Lytle Creek #1	1N4W24E01S	106	990	326	740 to 708 640 to 606 584 to 502 470 to 340 324 to 276	148	178

NI = No information.
All = Well exists completely in the upper aquifer.